CLINICAL RESEARCH STUDIES

From the Midwestern Vascular Surgical Society

Utility of left subclavian artery revascularization in association with endoluminal repair of acute and chronic thoracic aortic pathology

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Background: **A rapidly increasing number of thoracic aortic lesions are now treated by endoluminal exclusion by using stent grafts. Many of these lesions abut the great vessels and limit the length of the proximal landing zone. Various methods have been used to address this issue. We report our experience with subclavian artery revascularization in association with endoluminal repair of acute and chronic thoracic aortic pathology.**

Methods: **Thirty (43%) of 70 patients undergoing thoracic endovascular stent-graft placement from January 2001 to August 2005 had lesions adjacent to or involving the origin of the subclavian artery. The mean age was 62 years (range, 22-85 years; 63% were men, and 37% were women). This subgroup of 30 patients had indications for repair that included thoracic aortic aneurysm (n = 15), traumatic transection (n = 6), chronic dissection with pseudoaneurysm (n = 5), and acute dissection with intramural hematoma (n = 4). All 30 patients had the subclavian origin covered by the stent graft. In eight cases (27%), no effort was made to revascularize the subclavian artery before or during the endograft placement procedure. Twenty-three (77%) of 30 patients underwent subclavian to carotid artery transposition (n = 21) or bypass (n = 2) before (n = 12; average of 14 days before stent-graft placement), concomitant with (n = 10), or after (n = 1) the endovascular procedure. Physical examination and computed tomography scans were performed after surgery at 1, 6, and 12 months and annually thereafter. The mean follow-up was 18 months (range, 1-51 months).**

Results: **Five acute complications occurred in the eight patients (63%) who had the subclavian artery covered without pre-endograft revascularization and included four patients who experienced stroke (accounting for the only death) and one patient who developed symptomatic subclavian-vertebral steal that necessitated transposition 7 months later. Two (9%) of the 23 patients who had subclavian revascularization experienced left-sided vocal cord palsies, and 1 patient (4%) developed lower extremity paraparesis secondary to spinal cord ischemia. No late endoleaks related to retrograde sac perfusion from the most distal great vessel have been identified in any patient.**

Conclusions: **Subclavian revascularization procedures can be performed with relatively low risk. Complications are rare, and patient recovery is rapid. Although this is not necessary in all cases, we advocate subclavian to carotid transposition when the aortic lesion is within 15 mm of the left subclavian orifice to prevent type II endoleak or perfusion of a dissected false lumen when the ipsilateral vertebral artery is patent and dominant or when coronary revascularization using an ipsilateral internal mammary artery is anticipated and in cases that necessitate extensive coverage of intercostals that contribute to spinal cord perfusion. Carotid to subclavian artery bypass should be reserved for patients with a patent internal mammary artery conduit perfusing a coronary vessel and should be combined with proximal subclavian ligation.**
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The first thoracic endografts are now commercially available in the United States, and several others are undergoing refinement in phase II investigational device exemption trials.[1] Significant proportions of patients with both acute and chronic thoracic aortic disease who are evaluated for treatment with endovascular therapy are found to have pathology adjacent to the origin of the great vessels. Although open surgical repair remains a viable treatment alternative for many, management of such proximal disease requires very proximal aortic cross-clamping and occasionally hypothermic circulatory arrest to safely complete the proximal anastomosis. When patients are considered for endoluminal therapy, several different treatment paradigms have developed for managing proximal thoracic aortic pathology.[2,3] When pathology abuts the left subclavian ar-

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tery, some surgeons recommend extra-anatomic rerouting of cerebrovascular and upper extremity blood flow with subclavian-carotid transposition or bypass.[4-8] Others advocate simply ignoring this vessel and deploying the covered portion of the stent graft over the subclavian origin.[9-16] Branched and scalloped endografts are presently under development, and techniques to fenestrate the endograft material and deploy stents into the great vessels are being pioneered in some institutions.[17-19] There is no consensus regarding how best to handle cases with proximal thoracic aortic pathology. Most do agree that preventing significant proximal endoleaks is critical for durable success and that preserving vertebral and mammary circulation is important. We studied a subset of patients who presented with aortic pathology that was adjacent to the great vessels, in an attempt to develop guidelines for managing these important proximal aortic branches.

METHODS

Seventy patients (26 female and 44 male) underwent repair of thoracic aortic pathology including aneurysm (n = 38), acute dissection (n = 5), traumatic disruption (n = 14), pseudoaneurysm (n = 7), or intramural hematoma/ulceration (n = 6) at Northwestern Memorial Hospital before August 2005. Industry-manufactured devices were used in 38 cases, custom-fabricated grafts were used in 19 cases, and aortic extender cuffs designed for use in the infrarenal aorta were deployed in 13 cases.

The proximal extent of the aortic pathology involved or was adjacent to the great vessels in 30 (43%) of the 70 patients. This group included 19 men (63%) and 11 women (37%) with an average age of 58 years (range, 26-81 years). This subgroup of 30 patients had indications for repair that included thoracic aortic aneurysm (n = 15), traumatic transection (n = 6), chronic dissection with pseudoaneurysm (n = 5), and acute dissection with intramural hematoma (n = 4). In all 30 cases, the most distal aortic branch was covered by the proximal end of the stent graft.

At-risk subclavian vessels were managed by transposition into the adjacent common carotid artery before endograft deployment in 20 patients and by carotid to subclavian bypass with proximal subclavian ligation in 2 patients with an existing left internal mammary artery (LIMA) to coronary bypass. Care was taken to maintain antegrade or retrograde perfusion of all of the branches of the subclavian. The artery was transposed, or bypassed, on the same day that the endograft was placed, during the same anesthetic but before device deployment in 10 patients. The subclavian(s) were transposed at a separate operation before endograft placement in 12 patients (average, 14 days; range, 1-24 days before the endovascular procedure). This included 2 patients with aberrant right subclavian vessels who had both the right and left subclavian vessels transposed at separate settings before surgery (for a total of 24 subclavian vessels revascularized before endograft placement). All 22 patients then went on to have the subclavian artery origin covered by the stent graft, with successful obliteration of antegrade flow into the subclavian stump. One of the 22 patients who had preoperative subclavian transposition had the subclavian origin covered with the stent graft and the left common carotid artery covered with a proximal bare metal stent.

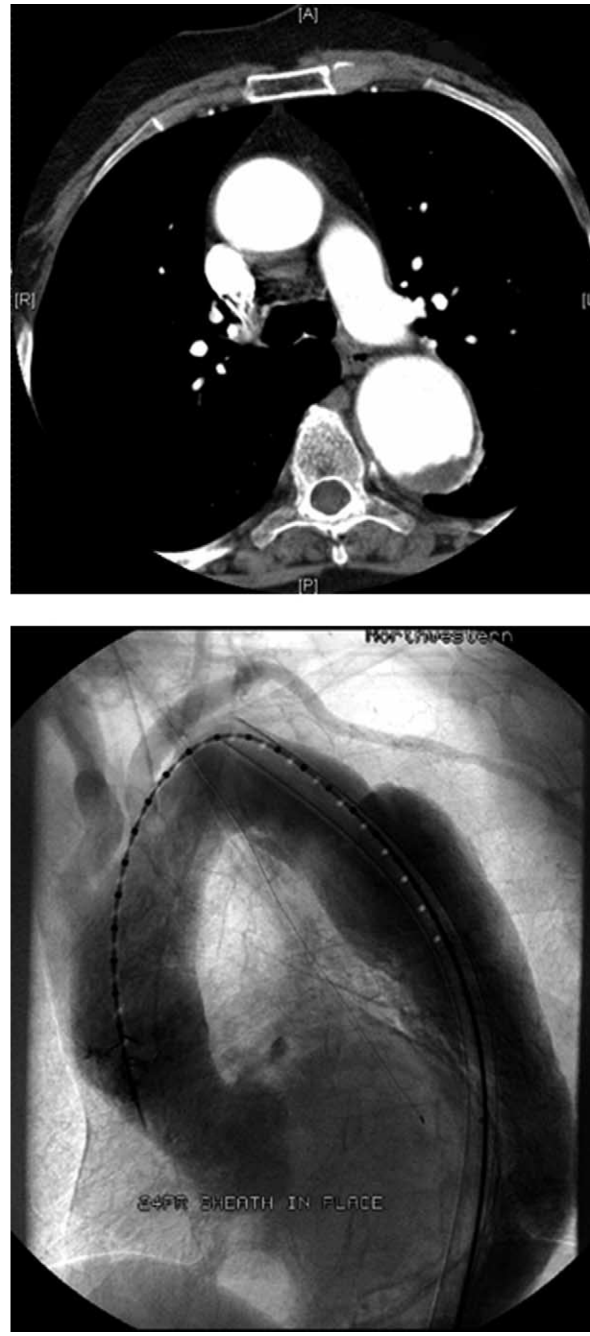

Fig 1. A, Contrast-enhanced computed tomography scan demonstrating aneurysmal degeneration of the descending thoracic aorta. **B,** Corresponding intraoperative angiogram.

Eight patients had a nonrevascularized subclavian origin covered by the proximal end of the stent graft, and no attempt was made to reconstruct the branch vessel before

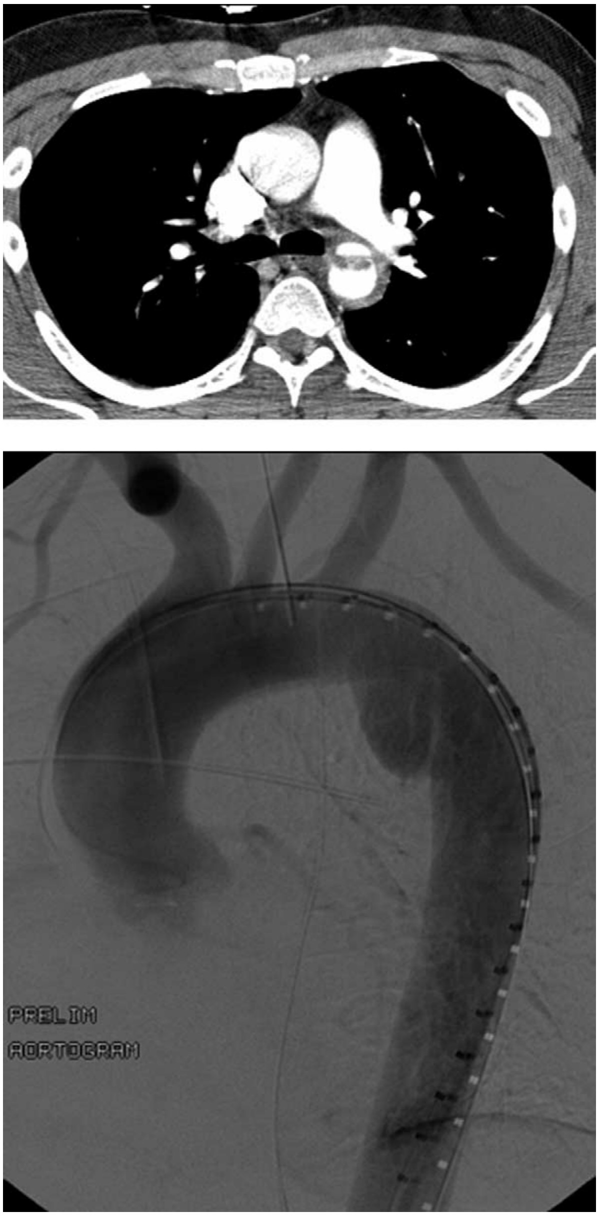

Fig 2. A, Contrast-enhanced computed tomography scan of the chest demonstrating an acute traumatic transection of the descending thoracic aorta. **B,** Corresponding intraoperative angiogram.

the endograft was deployed. A single patient from this group, counted below as the 23rd revascularized patient, required subclavian artery to common carotid artery transposition 7 months after endograft placement. This patient is discussed in more detail in the next section.

Data were maintained prospectively in an institution-specific database as well as in alternate databases kept as mandated by our industry partners during phase II trials. This information was then reviewed retrospectively from these prospectively maintained databases according to guidelines indicated by the Northwestern University Medical School Institutional Review Board.

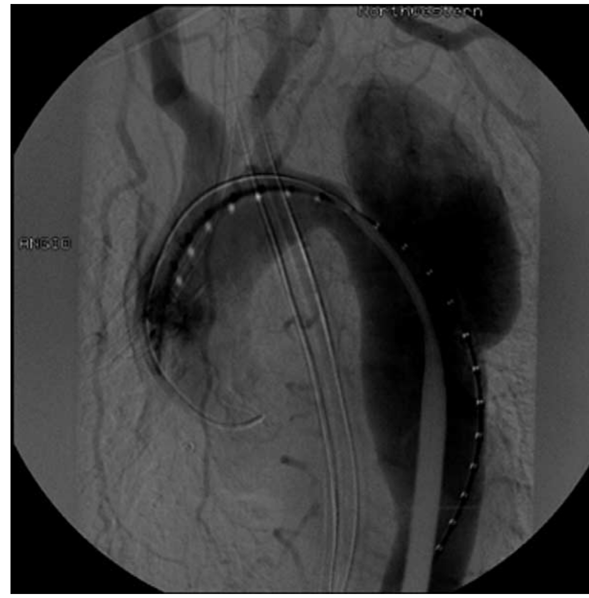

Fig 3. Intraoperative angiogram demonstrating pseudoaneurysm formation of the descending thoracic aorta in the setting of a chronic aortic dissection.

All patients underwent a thorough physical examination, including bilateral upper extremity blood pressure measurements and determination of the ankle-brachial index, before surgery, after surgery in the recovery room, and daily during the hospitalization. Outpatient follow-up consisted of an evaluation at 1, 6, and 12 months and yearly thereafter. Twenty-seven (90%) of 30 patients in whom the proximal extent of the aortic pathology involved or was adjacent to the great vessels attended a 1-month follow-up, where they underwent a complete physical examination with determination of the ankle-brachial index, plain chest radiographs, and a chest computed tomography scan. Of the 13 eligible patients, 10 (77%) have attended the 6-month follow-up, and 5 have been re-examined 1 year or more after treatment.

RESULTS

One (1.4%) of the 70 patients died within 30 days of surgery from stroke. This patient is described in more detail below. Additional periprocedural complications directly related to endograft therapy included four (6%) more strokes, two (3%) cases of access site limb ischemia, two (3%) cases of spinal cord ischemia with paraparesis, two (3%) retroperitoneal bleeds, and, as previously noted, one (1%) case of symptomatic subclavian steal. Five (7%) late deaths have occurred: from sepsis (n = 1), perforated viscus (n = 1), and congestive heart failure (n = 1) and after open ascending aortic aneurysm repair (n = 2).

Eight (27%) early complications developed in the subgroup of 30 patients with proximal thoracic pathology. Five (63%) complications occurred in the eight patients who had the nontransposed subclavian origin covered at the time of

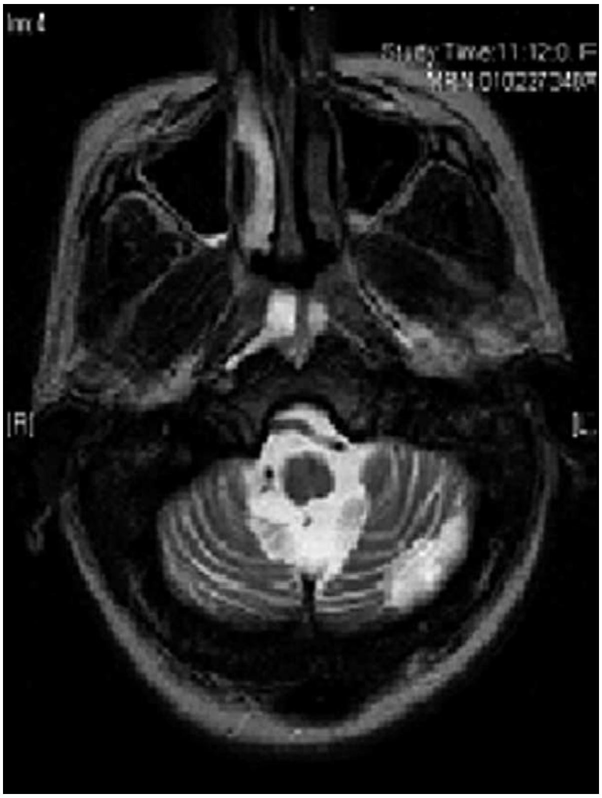

Fig 4. Magnetic resonance imaging of the brain demonstrating an isolated left posterior circulation infarction.

Fig 5. Angiographic appearance of a completed left subclavian artery to left common carotid artery transposition with contrast filling the residual subclavian stump.

endograft deployment. One patient, mentioned previously, developed symptoms of subclavian-vertebral steal, including arm fatigue/pain and syncope, shortly after endograft placement and left subclavian coverage. The symptoms did not resolve with time, and this patient required subclavian revascularization via subclavian to carotid transposition 7 months after the endograft procedure for treatment of ongoing posterior circulation ischemia. Four patients experienced stroke. One of the four patients developed a large left middle cerebral distribution infarct, likely due to atheroembolization from the aortic arch, and died within days of the endograft placement. Three patients developed magnetic resonance imaging–confirmed posterior circulation strokes. In two of these cases, the infarcts were confined to the distribution of the posterior circulation and ipsilateral to the covered subclavian artery. Upon further review of available imaging, the contralateral vertebral artery was absent in both cases. The third patient had multiple, small, bilateral anterior and posterior circulation infarcts, again likely due to diffuse atheroembolization. To date, no other patients have voiced significant complaints related to arm or brain ischemia. Furthermore, no late endoleaks resulting from retrograde subclavian flow have been identified.

Among the 21 patients undergoing 23 (including 2 staged, bilateral procedures in the patients with aberrant anatomy) subclavian to carotid artery transposition procedures before or after endograft placement and the 2 patients who had pre-endograft carotid-subclavian bypass, there were 2 (8%) complications directly related to the subclavian revascularization procedure. Both were temporary left-sided vocal cord palsies, and both were assumed to be related to traction on the vagus and/or recurrent nerve during the revascularization procedure. The paralyzed vocal cords were confirmed by indirect laryngoscopy. There was spontaneous clinical resolution of one palsy after 3 months. The second patient underwent successful vocal cord medialization 6 weeks after the event. A third patient from this group experienced delayed spinal cord ischemia and lower extremity paraparesis after endograft placement that was unrelated to the subclavian revascularization. There were no strokes or procedure-related deaths in this group. All 23 subclavian to carotid artery transpositions and both bypass grafts remain patent at a mean follow-up of 18 months (range, 1-51 months). No late morbidity related to these procedures has occurred. In all transposition cases, the subclavian stump(s) have thrombosed. In one of two bypass cases, the subclavian was seen on computed tomography to fill retrograde all the way to the device, although no type II leak could be identified.

A single stroke occurred in the group of 40 patients with thoracic aortic pathology distal to the great vessels. In this group of patients, in whom the endograft device was deployed well beyond the aortic arch and no manipulation of the great vessels was necessary, the stoke rate was lower than it was in the 30 patients with pathology adjacent to the

Table. Summary of the current literature, demonstrating a 23% complication rate in patients who underwent coverage of the left subclavian orifice by a thoracic endograft as compared with a 3% complication rate when the left subclavian artery was revascularized

Study	*Proximal aortic cases*	*Subclavian covered*	*Outcome/complications*	*Subclavian transposed*	*Outcome/complications*
Mitchell[20]	13	2	1 Neurologic	11	No complications
Grabenwoger[8]	9	0	No complications	9	No complications
Moore[15]	1	0	No complications	1	No complications
Hausegger[10]	6	4	No complications	2	No complications
Cambria[13]	6	0	No complications	6	No complications
Criado[2]	13	5	No complications	8	1 lymphatic
Criado[3]	9	2	No complications	7	No complications
Gorich[9]	22	21	4 neurologic, 4 endoleaks, 2 arm, 1 spinal	1	No complications
Heijman[7]	5	0	No complications	5	No complications
Burks[16]	3	1	No complications	2	No complications
Tiesenhausen[11]	10	8	3 neurologic, 2 endoleaks	2	No complications
Lambrechts[14]	7	6	No complications	1	No complications
Hutton[21]	1	1	1 neurologic	0	No complications
Hansen[22]	4	4	No complications	0	No complications
Leurs[23]	79	42	1 neurologic	37	No complications
Northwestern	30	8	4 neurologic, 1 arm	22	2 recurrent nerve injuries
Totals	218	104	24 (23%)	114	3 (3%)

arch vessels (2.5% vs 13%). This difference did not reach statistical significance ($P = .15$).

DISCUSSION

Thoracic endografts are undergoing refinement in phase II and postmarketing trials in the United States.[1] Industry-manufactured devices have been or are currently being tested for treatment of thoracic aortic aneurysms. The first of these devices, the Gore Thoracic Excluder (W.L. Gore & Associates, Inc., Tempe, AZ), has recently gained approval from the Food and Drug Administration to treat aneurysmal pathology. These industry-manufactured devices, some custom-made devices, and extender cuffs designed for use in the infrarenal aorta have been used off-label or with physician-sponsored investigational device exemptions to treat acute dissections, solitary aortic ulcers, and traumatic transections in the United States.

Although various types of pathology, and certainly some aneurysms, may abut the left subclavian artery, certain disease processes—namely, traumatic transection and dissection—nearly always develop within close proximity to the origin of the great vessels. In our experience, 30 (43%) of 70 patients undergoing endovascular repair of acute or chronic thoracic aortic pathology had lesions that were adjacent to or involved the origin of the great vessels. This underscores the importance of being able to safely position endoluminal devices high in the descending thoracic aorta or even with extension into the aortic arch if we are to use endovascular techniques to treat these lesions. Alternative treatment paradigms have been devised to address proximal aortic pathology involving the great vessels, but only some include techniques to maintain normal perfusion to the head and arms. An informal review of a random segment of the current endograft literature showed a combined 23% complication rate when the left subclavian artery orifice was covered, compared with a 3% complication rate when flow into the left subclavian artery was preserved. The difference in neurologic outcome is most noteworthy (Table).[2,3,7-11,13-16,20-23]

Several published series have specifically addressed the topic of proximal thoracic aortic pathology, but it seems that no consensus has arisen on how best to treat these patients. Some groups have sought to lengthen the proximal landing zones via transposition procedures, whereas others have advocated carotid to carotid, femoral to subclavian, or carotid to subclavian bypass.[4-8] Although the bypass procedures may address the issue of lengthening the proximal neck to ensure an adequate seal zone, they generate the potential for type II endoleak and continued perfusion of the sac in the setting of aneurysmal disease or of the false lumen in the case of dissection. Other groups have demonstrated success with techniques designed to maintain normal branch perfusion with scallop-edged and bare metal–ended stent grafts or with endograft fenestration and retrograde stent deployment.[15,16,19,24] Although they are novel solutions, these techniques clearly add a new level of complexity to endovascular aortic repair. Branched endovascular prostheses are presently being developed, but, again, these advancements make device deployment more intricate, and widespread acceptance is likely a few years away.[17,18]

Perhaps the added complexity of branch vessel management is unnecessary and coverage of the great vessel origins, at least the left subclavian, can be routinely performed with impunity. Indeed, some groups have suggested that coverage of the left subclavian artery is safe and well tolerated and that extra-anatomic bypass or transposition should be reserved only for patients who develop symptoms that necessitate intervention.[9-16] Clearly there are real advantages to coverage without perioperative great vessel revascularization. In the setting of traumatic aortic transection and other unstable situations in which urgent intervention is mandated, an added procedure before emergent lifesaving endovascular intervention may be prohibitive. Additionally, much to the dismay of some groups, although appealing to others, the services of a vascular surgeon and the availability of an operating room, both necessary for performing bypass or transposition procedures, would not be required. In several instances, our patients underwent an additional anesthetic for the transposition procedure, but in most cases this can be eliminated if the open and endovascular procedures are performed concomitantly.

Despite the potential advantages of simplifying the thoracic endorepair, our experience has led us to advocate, in certain situations and with particular anatomic findings, the rerouting of great vessel blood flow before endoluminal repair of thoracic aortic lesions is undertaken. In fact, in our series, five of eight patients who were treated by simply covering the subclavian origin without revascularization developed adverse events. Four of these events were strokes that occurred in the immediate postoperative period. Although we cannot state with certainty that these could have been prevented by antecedent transposition, and although one certainly could argue that proximal disease is simply a marker for increased stroke risk overall, two isolated posterior circulation events would certainly suggest that ipsilateral vertebral perfusion remains critical. The fifth patient, who required late subclavian revascularization for persistent posterior circulation symptoms, adds credence to this concern.

In cases of proximal thoracic aortic pathology arising within 15 mm of the most distal great vessel, especially when the dominant vertebral artery (the vertebral contralateral to one that is hypoplastic or absent or ends prematurely in a cerebellar branch without contributing to the basilar artery) arises from the ipsilateral subclavian vessel, prophylactic branch revascularization should be considered before endovascular repair. The ability to maintain normal perfusion and prevent ischemia of the upper extremity via the subclavian and of the brainstem via the ipsilateral vertebral artery are obvious benefits. We also use pre-endograft subclavian revascularization when multiple intercostal vessels will be covered in patients with extensive descending thoracic aortic pathology. This may, in theory, help protect against spinal cord ischemia by preserving important vertebral artery collaterals that contribute to spinal blood flow. Patients who may undergo future coronary revascularization with a LIMA should undergo transposition to preserve antegrade flow into the coronary bypass conduit. Patients who have already had LIMA reconstruction require carotid to subclavian bypass (rather than transposition, because this requires unsafe clamping proximal to the LIMA) when the origin of the subclavian is to be covered. Finally, patients with very proximal aneurysms or type B dissections may require definitive management of the great vessels to prevent type II endoleak or continued perfusion of a dissected false lumen from retrograde subclavian blood flow. This should be accomplished by subclavian transposition proximal to any branches to eliminate all retrograde perfusion. Alternatively, if a carotid to subclavian bypass is chosen, the subclavian origin must be endoluminally occluded or ligated proximal to any branches for the same reason.

We prefer transposition over bypass because it is the most logical approach in most cases. First, the addition of the proximal subclavian artery ligation that is necessary to eliminate endoleak potential after bypass requires the same exposure as transposition. Unlike with a bypass, the exposure for transposition, when properly performed, does not risk injury to the phrenic nerve, and transposition avoids the use of a prosthetic conduit in the neck. Finally, transposition is a more durable reconstruction when compared with bypass. In addition to the 100% patency rates at 18-month follow-up in this series, the safety, efficacy, and superior durability of subclavian to carotid transposition are well established.[25,26]

Although perhaps not necessary in every case, subclavian revascularization provides some advantages over great vessel coverage, and in the 22 patients in this series in whom subclavian transposition(s) or bypass preceded endograft placement and in the single patient who had the delayed transposition, the procedure(s) were well tolerated. The risks associated with subclavian transposition in experienced hands are low, and the advantages over carotid to subclavian bypass are real.[25,26] However, when great vessel revascularization is desired and transposition is contraindicated, a bypass should be considered rather than simply covering the great vessel origins.

At this time, in semiurgent and elective proximal thoracic cases, when time permits, we elect to image supraaortic trunk and extracranial and intracranial cerebrovasculature before endorepair. We prefer magnetic resonance angiography, but computed tomography and vascular ultrasonography may also suffice. When there are indications for great vessel revascularization, as outlined previously, we proceed with elective transposition immediately before endorepair. Bypass is rarely used. In truly emergent cases, we attempt to visualize all the supraaortic trunks at the time of the intraoperative predeployment angiogram, accept the risk, and deploy the device across the subclavian. We will then transpose the vessel on a later date as clinical circumstances suggest.

CONCLUSION

The ability to provide minimally invasive endovascular treatment for acute and chronic thoracic aortic diseases seems to hold great promise. Optimal and appropriate management of arch vessels in cases that involve proximal descending aortic pathology should minimize unnecessary ischemic complications and help provide for a more durable repair.

AUTHOR CONTRIBUTION

Conception and design: BGP, MKE, TGG, MDM
Analysis and interpretation: BGP, MDM
Data collection: BGP, MDM
Writing the article: BGP, MDM

Critical revision of the article: BGP, MKE, TGG, MDM
Final approval of the article: BGP, MKE, TGG, MDM
Statistical analysis: BGP, MDM
Obtained funding: MDM
Overall responsibility: MDM

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